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MODIFICATION OF THE TIGRIS IMAGE-ORTHICON CAMERA SYSTEM

FINAL REPORT

Prepared for

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PREFACE

This is the final engineering report describing the development, testing, and demonstration of improvements in the ultrasensitive TIGRIS Image-Orthicon Television Camera. The work was performed under the technical direction of NASA Headquarters, Office of Space Sciences, Physics and Astronomy Programs, Code SG, Washington, D.C., under contract No. NASW-1342. The report describes the work performed by the Astro-Electronics Division of the Radio Corporation of America during the period March through August 1966 and is supplied in accordance with the requirements of Article IX, Item 4, of the contract. The recommendations phase of the work is summarized in this report, but separate detailed reports have been issued.

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INTRODUCTION AND SUMMARY

This is the final engineering report on a 5-month program to increase the performance and flexibility of the high-sensitivity image-orthicon television camera system, developed under the TIGRIS Program*. With these improvements in performance, the TIGRIS Image-Orthicon Camera System is suitable for use in a wider range of scientific missions than had previously been planned. The TIGRIS slow scan television camera is adaptable for satellite, aircraft, ground, or underwater applications where the scene illumination is below the threshold sensitivity of the eye or where extremely long exposures are required with "fast" films.

A. BACKGROUND

Work on the TIGRIS Program was started in October 1963. The object of this program was to develop and fabricate a preprototype model of a very sensitive television camera system that would have the ability to obtain images of diffuse light-scattering regions in the solar system. Although it has been possible to detect the luminosity of outlying regions in the solar corona, the zodiacal light, and the gegenschein from earth-based observations, only the strongest of these light sources could be seen, due to the limitation of the diffuse luminosity of the ionosphere. The objective of the TIGRIS Program was to use an extremely sensitive television camera system to obtain pictures above the ionospheric luminescent layers of the weaker light sources during a suborbital trajectory that would last for approximately twelve minutes.

The preprototype camera system was designed and built and has successfully met all the requirements of the contractual laboratory acceptance tests. Field tests, conducted at Capillo Peak Observatory in New Mexico in 1964, proved the high sensitivity of the camera system. The night air glow and the zodiacal light were clearly visible in the photographs taken. It is estimated that stars of a +10 magnitude were seen. Certain undesirable effects such as minor shading problems

* Contract No. NASW-823, "Televised Images of Gaseous Regions in Interplanetary Space". This work was performed under the technical direction of the Center for Radio Physics and Space Research at Cornell University by the Astro-Electronics Division of the Radio Corporation of America, Princeton, New Jersey.

and black halation, which is typical of an image-orthicon tube, were noted. Under the current contract with NASA, the objectives were to advance the capabilities of the preprototype camera, enhancing its suitability for a wide range of uses, and to search for solutions to the problems in shading and black halation.

B. PROGRAM SUMMARY

1. Modifications

Improvements have been incorporated into the TIGRIS preprototype, resulting in a versatile, ultrasensitive, slow-scan TV camera suitable for satellite, ground, or underwater applications.

The improvements include the incorporation of an electronic shutter, beam-current control, and additional magnetic shielding. Two methods of beam-current control were developed: (1) an anode sample regulator for long missions, and (2) a cathode-current regulator for short missions. An electronic shutter was developed that will permit continuously variable exposure times over the range of 125 milliseconds to 16 seconds. Additional magnetic shielding has been added so that acceptable performance is possible in a 2-gauss peak-to-peak magnetic field. The earth's magnetic field is 0.6 gauss, or effectively 1.2 gauss peak-to-peak in a rotating vehicle.

In addition, an investigation of shading, automatic-exposure control, and black halation was made and recommendations based on the results of the investigation were prepared.

A threshold sensitivity of 10^{-9} footcandle on the photocathode has been measured at a 16-second exposure interval.

Typical applications for this camera include observation of (1) star-fields, (2) night cloud cover, (3) star-illuminated scenes, and (4) gaseous regions in space. The camera can also be used for recording spectrometric data, and, if used in conjunction with image converters, it can be used for recording low-level x-ray radiation or obtaining thermal pictures.

The TIGRIS television camera consists of two major assemblies: the camera electronics assembly and the camera sensor assembly, which is usually mounted coaxially inside the electronics assembly.

Some of the operating characteristics and performance specifications of the TIGRIS camera system are given in Table I.

TABLE I. OPERATING AND PERFORMANCE DATA

Electronic shutter	Exposure time continuously variable from 125 ms to 16 sec	
Resolution: at 2-sec exposure	500 TV lines at 5×10^{-6} footcandle on photocathode	
	200 TV lines at 2.5×10^{-7} footcandle on photocathode	
S/N ratio: 2-sec exposure and 5×10^{-6} footcandle	26.4 db (p-p signal/RMS noise)	
Gray-scale steps	10 (0.15 density/step)	
Optics	Zeiss	Farrand Optical
Focal length	25 mm	76 mm
Numerical aperture	2.8	0.87
Field of view	80°	26°
Readout frame time	2 sec	
Line rate	250 cps	
Lines/frame	500 nominal, less blanking	
Aspect ratio	1/1	
Output	White: positive, 4 V adjustable	
	Sync tip: 0 V	
	Black: 1.25 V adjustable	
D-C input	28 V at 1.8 amp	
Weight	40 lb	
Magnetic shielding	Permits operation in a 2-gauss p-p rotating field	
Beam-current control	Permits unattended operation for long periods of time	

2. Investigations and Recommendations

The investigation and recommendations phase of the work has been detailed in separate reports, but a brief summary is shown here.

a. Shading

Shading is due primarily to the wide-angle optics employed in the original TIGRIS camera. For some missions, the problem could be eliminated by the use of narrow-angle optics. For other missions, optical shading correction could be incorporated. Electronic shading correction can also be provided, either in the satellite or on the ground. The appropriate recommendation is dependent on the mission.

b. Automatic Exposure Control

It is recommended that an automatic exposure control system be tried on the TIGRIS camera. This system would be operated by detecting a signal corresponding to the peak highlight in the scene and would have an output which controls the duration of the exposure by means of the electronics shutter. The electronic shutter has been incorporated into the TIGRIS camera as one of the modifications required by the present contract.

c. Black Halation

The major cause of black halation is a result of redistribution of secondary electrons from the bright areas of the target falling back on the darker areas. The recommendations include the use of a close-spaced elcon-glass-target image orthicon, or for even better performance, the use of a close-spaced, elcon-glass-target image isocon. Video feedback to the control grid or target of the image orthicon may be beneficial.

Other recommendations resulting from the contract investigations are given in Section V of this report.

SECTION II

DESCRIPTION OF DEVELOPMENT (OUTLINE OF PROGRAM)

A. GENERAL

(1) The contract was reviewed and accepted.

(2) The design group was staffed.

(3) General-purpose test equipment was assigned for the duration of the project.

(4) An internal schedule was prepared to allow project review by management on a regular basis.

(5) Members of the RCA David Sarnoff Research Laboratories were consulted frequently during the program. The image orthicon vendor was also consulted.

(6) The block diagrams of beam-current control systems were developed.

(7) The block diagrams of electronic shutter systems were developed.

(8) The image orthicon parameter measurements were made. The close-spaced Z 7850 failed with an open heater during the course of these measurements. It was replaced with a borrowed tube.

(9) The designs were completed.

(10) The components were purchased.

(11) The designs were breadboarded and tested.

(12) The magnetic disturbance measurements were conducted.

(13) The recommendations were prepared.

(14) The new circuit boards were fabricated (beam control and electronic shutter).

(15) The preprototype was modified to accept the new circuit boards.

(16) The magnetic shield was incorporated.

(17) The system measurements were made.

(18) The system was demonstrated.

B. BEAM CURRENT CONTROL

1. Measurements

To define the requirements of the beam-control circuits, the manufacturers of the image orthicon were consulted and their data reviewed. In addition the following measurements were completed:

a. The cathode current versus G1 bias (Figure 1) was measured to determine the normal operating range required for the beam-current regulator. It was determined that the G1 cutoff voltage varies from -60 volts to -110 volts, and that the normal cathode current is only 40 nanoamperes.

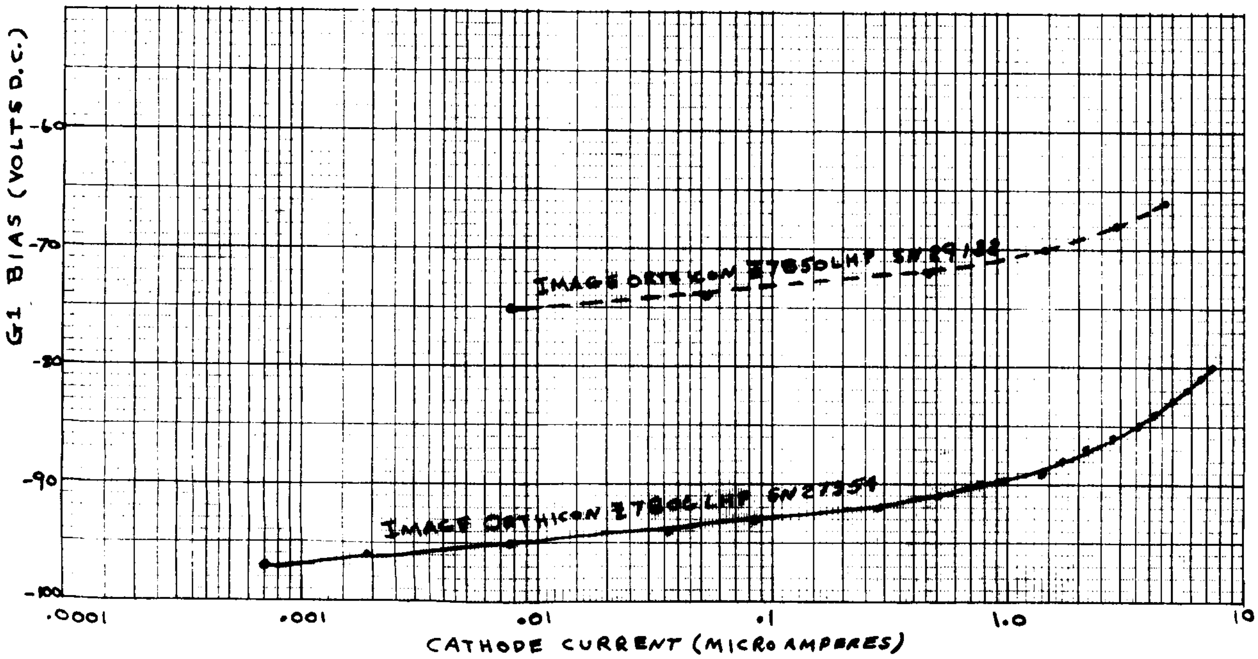


Figure 1. Cathode Current vs G1 Bias

b. The cathode current versus G1 bias for varying filament voltage, shown in Figure 2, was measured to simulate the change in emission during life so that the required operating range of the beam-current regulator could be determined.

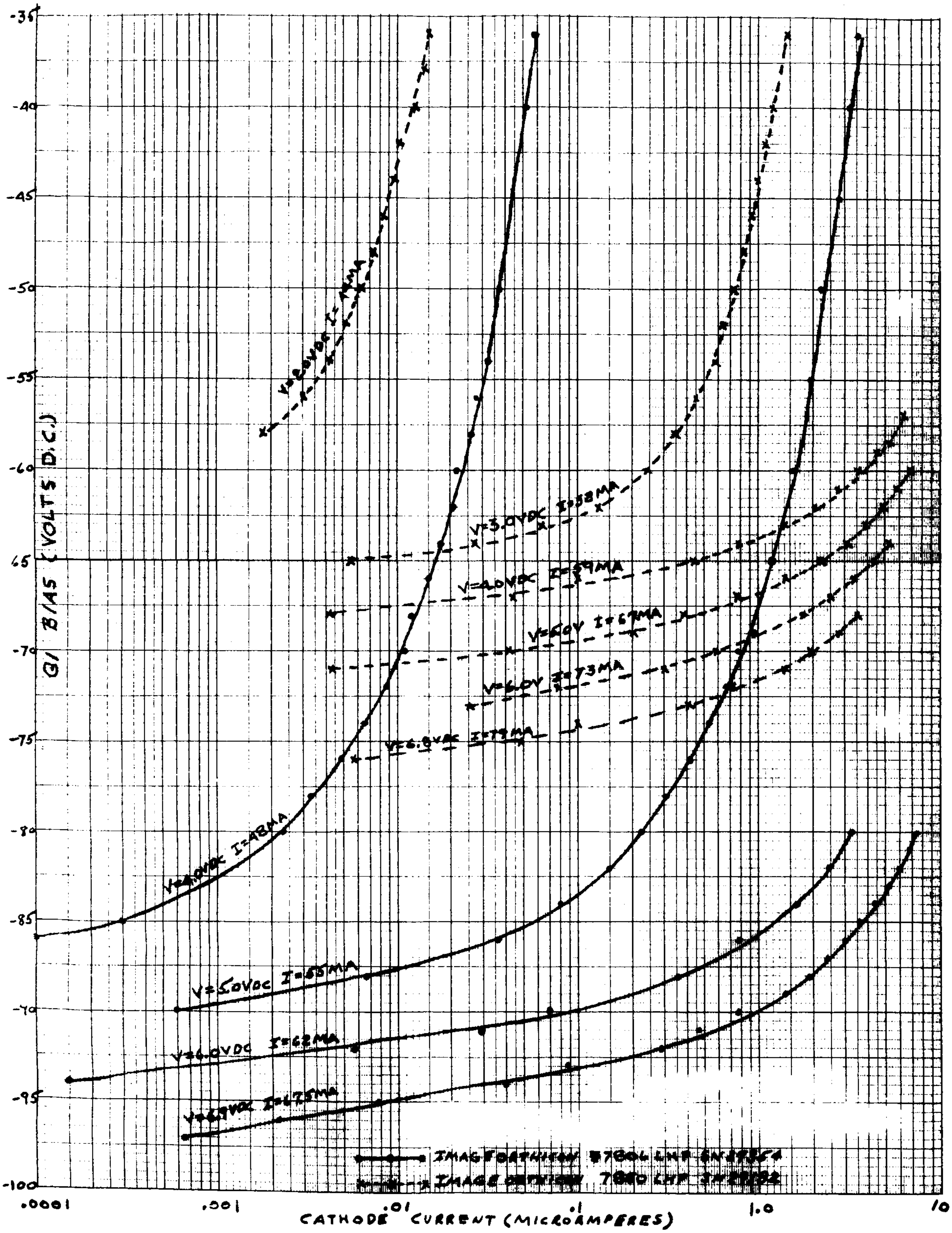


Figure 2. Cathode Current vs. G1 Bias (Filament Volts and Current as Parameter)

c. Views A, B, and C of Figure 3 show plots of multiplier anode current and signal-to-noise ratio versus photocathode highlight illumination for two different image orthicons. These measurements were made under open-shutter conditions to determine the peak-to-peak signal current available for the anode-sample beam-current regulator type of control system.

2. Design

It became apparent from the measurements that two methods of regulation should be developed, the choice determined by the mission requirements.

a. Anode-Sample Regulator

The first method of beam-current control consists of sampling the output of the video signal from the camera preamplifier in a sample-and-hold circuit and applying its output to a comparator. The output of the comparator operates a G1 control circuit. This type is preferred on long missions.

b. Cathode-Current Regulator

The second method consists of amplifying the d-c cathode current of the image orthicon and applying the amplified current to a comparator. The output of the comparator operates a G1 control circuit. This type is preferred on short missions.

The relative advantages and disadvantages of the two methods are shown in Table II. The optimum method chosen is dependent on the mission.

3. Circuit Description

a. Anode Sample Regulator

A block diagram of the anode-sample beam-current regulator is shown in block diagram, Figure 4. The anode sample regulator consists of: video preamplifier, buffer, driven clamp, sample and hold, cathode-blanking generator and switch, differential-amplifier-type comparator, d-c reference, level shifter, and G1-drive amplifier. The beam current is measured during the horizontal blanking interval by the following sequence of events:

(1) The image-orthicon target is blanked during the horizontal blanking interval. At the same time, the beam current of the image orthicon is cut off for approximately one-half of the blanking interval by applying a positive pulse to the cathode of the image orthicon, derived from the cathode-blanking generator. This event results in a peak-white reference signal.

(2) The beam current is then turned on while the target is still at cutoff, resulting in a reference black signal.

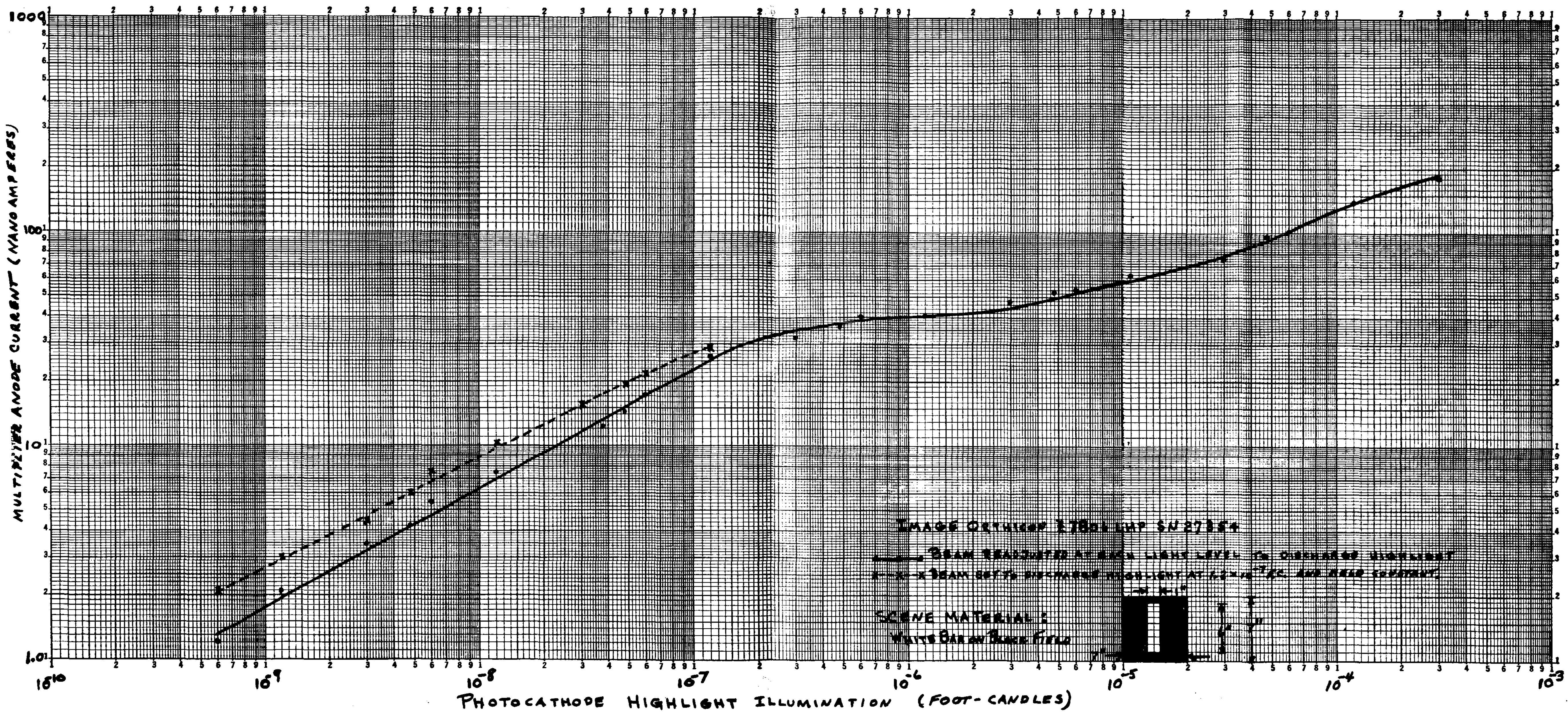


Figure 3A. Open Shutter Multiplier Anode Current vs. Photocathode Highlight Illumination

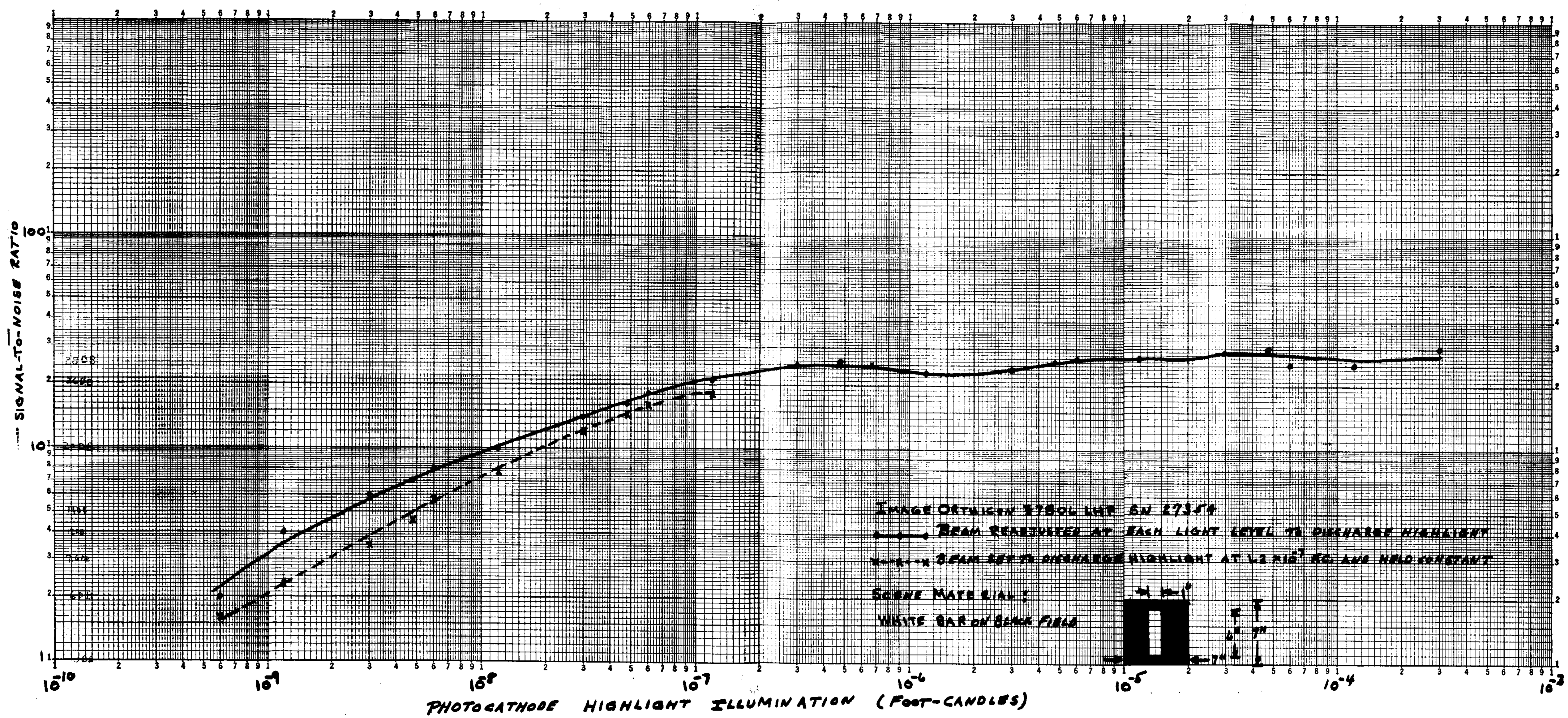


Figure 3B. Open Shutter Signal-to-Noise Ratio vs. Photocathode Highlight Illumination

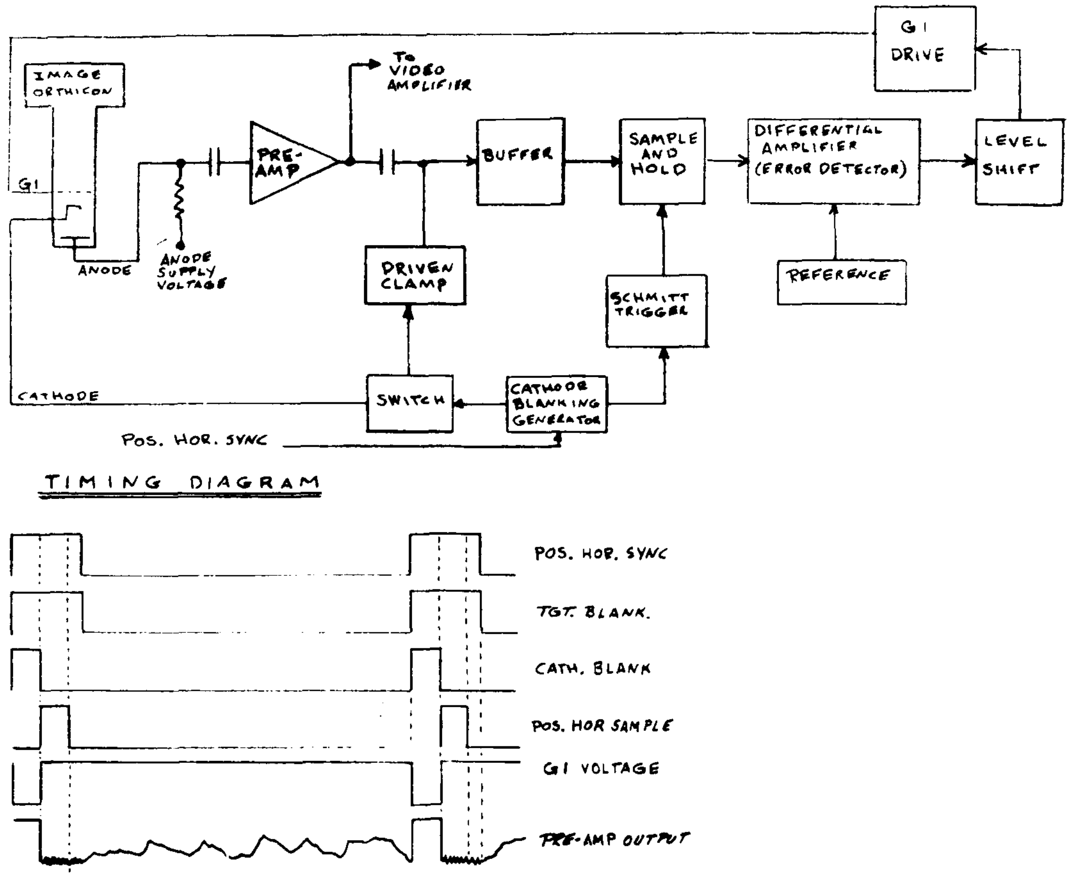


Figure 4. Anode-Sample Beam-Current Regulator, Block Diagram

This peak (white-to-black) signal is amplified in the video preamplifier and detected in the sample-and-hold circuit. The output of the sample-and-hold circuit is connected to the comparator. The output of the comparator is then level-shifted and connected to the image-orthicon grid number 1. A schematic diagram of the anode-sample beam-current regulator is shown in Figure 5.

The loading edge of positive horizontal sync (P10-11) is used to generate a short positive pulse by the cathode-blanking generator (Q2, Q5).

This positive pulse is approximately one-half the pulse width of positive horizontal sync. The output of the cathode-blanking generator is coupled to the cathode-blanking switch (Q12 and Q13) through amplifier Q9. The output of the cathode-blanking switch is connected to the image-orthicon cathode through P10-2 and also is coupled to a one-shot multivibrator, located on the video amplifier and target-blanking board, through P10-16. The trailing edge of this cathode-blanking pulse triggers the one-shot multivibrator in BI-P4 board. The multivibrator output pulse is somewhat less than one-half the pulse width of

TABLE II. COMPARISON OF TWO METHODS OF BEAM-CURRENT REGULATION

Anode Sample Regulator	Cathode Current Regulator
Advantages	
(1) No additional power supplies required. (2) Samples video output signal and can compensate either for variations in current division from G2 to main beam as result of alignment changes, or beam size variation with changing G1 bias. (3) Cathode leakage current does not interfere with regulation.	(1) Dynamic range required for preamplifier and main video amplifier is reduced. (2) Changes in dynode gain or video preamplifier gain will not change the beam current.
Disadvantages	
(1) Large dynamic range required for preamplifier because of low beam modulation in an image orthicon. This would not be the case if an image isocon were used as the sensor. (2) Requires delay of readout after integration. (3) Has longer settling time from a cold start, or after integration. (4) Changes in dynode or video preamplifier gain will change beam current.	(1) Requires additional power supply potentials. (2) Cathode leakage current can cause false regulation, particularly at very low beam currents. (3) Variations in current division from G2 to main beam are not regulated.
Recommended Use	
(1) Long missions, such as orbital types. (2) For very low cathode current types of image orthicons.	(1) Short missions, such as sub-orbital flight. (2) For high cathode current type image orthicons. (3) For rapid scan camera systems.

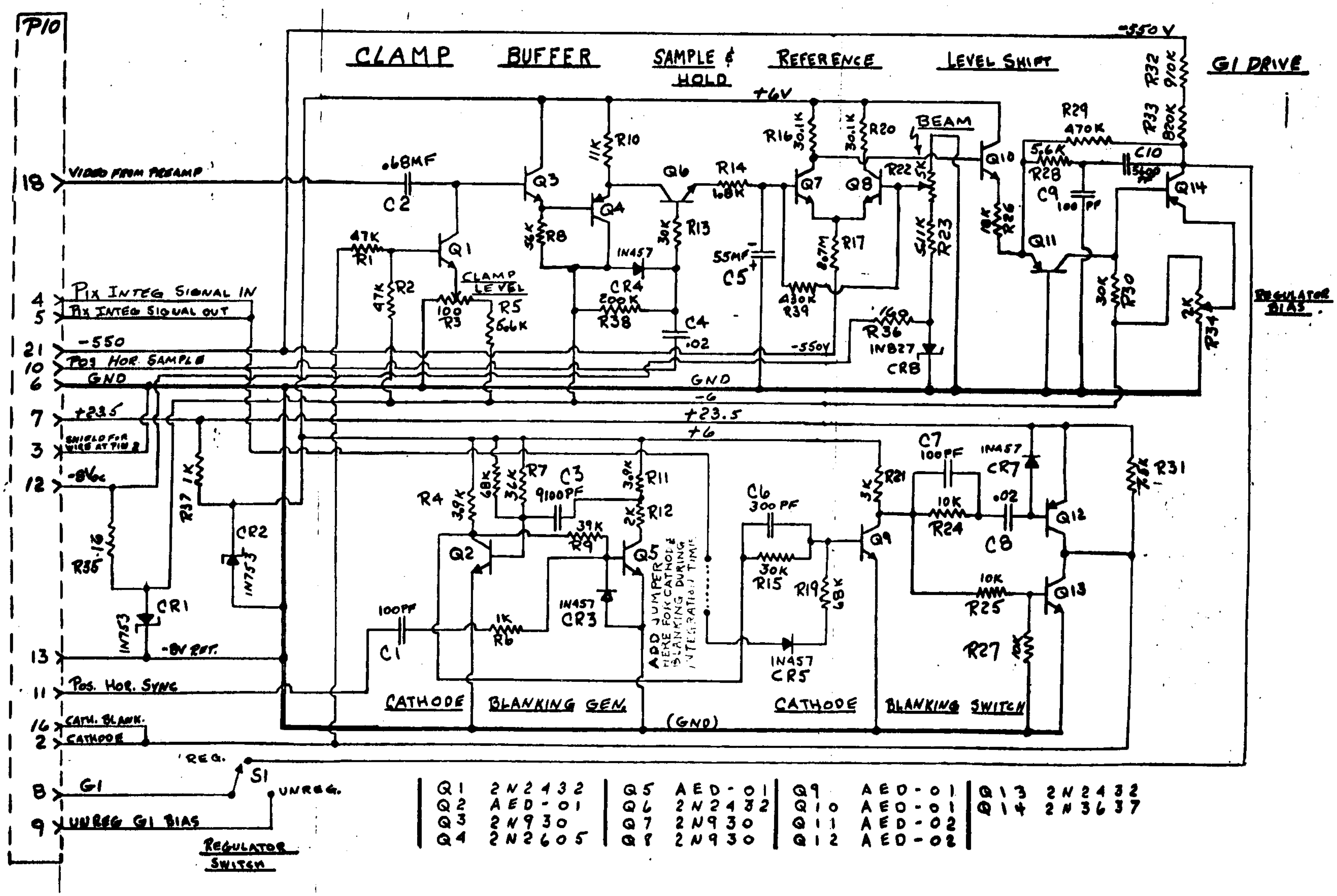


Figure 5. Anode-Sample Beam-Current Regulator, Schematic Diagram

positive horizontal sync. This output is used to close sample-and-hold switch Q6 and to charge C5. During this closure of Q6, the magnitude of the image-orthicon beam is measured; the measured value being the difference between zero return beam and the required preset value of the image-orthicon beam determined by beam control R22. (The zero beam reference is obtained during the time when target blanking and cathode blanking are coincident.) When the cathode is unblanked and target blanking is present, the beam is sampled as indicated above.

At the end of the positive horizontal sample pulse, Q6 is opened. The voltage on C5 is compared to a reference voltage (determined by R22) in comparator Q7, Q8. The difference voltage is level-shifted by Q10 and Q11 and drives Q14 which is coupled to G1 of the image orthicon. The difference voltage is therefore amplified through Q14 and keeps G1 at a value to maintain the beam constant at the preset value.

Clamp level control R3 is adjusted to provide a ground reference at the output of Q4 during the zero-return-beam time mentioned above.

The regulator bias control R34 sets the operating point of Q14, depending on the nominal G1 voltage required by the particular image orthicon tube being used.

The regulator switch permits either regulated beam control by the regulator or unregulated beam control from the G1 bias potentiometer on board BO-P3.

b. Cathode Current Regulator

As shown in Figure 6, the cathode-current regulator consists of: (1) a cathode-current detector, (2) a chopper-stabilized amplifier, (3) a differential-amplifier type of comparator, (4) a d-c reference, (5) a level shifter, and (6) a high-frequency d-c/d-c converter to provide the potentials required for the chopper-stabilized amplifier.

The schematic for the cathode-current regulator is shown in Figure 7.

The chopper-stabilized amplifier is denoted as X in the schematic. It is an Analog Devices Model 210, which uses a solid-state chopper to reduce voltage drift to 1 microvolt per $^{\circ}$C and to limit current drift to 2 picoamperes per 3 $^{\circ}$C. The amplifier has a nominal open-loop voltage gain of 10^8, and an open-loop input resistance of 0.5×10^6 ohms. Input noise voltage (dc to 1 Hz) and noise current is $5(10^{-6})$ volt and $10(10^{-12})$ ampere, respectively. The closed-loop input resistance is thus equal to 0.1 megohm, as determined by R2. The closed-loop gain is one hundred. ($A_V = R6/R2$). The input voltage developed across R2 is amplified by X and connected to the comparator Q3. The output

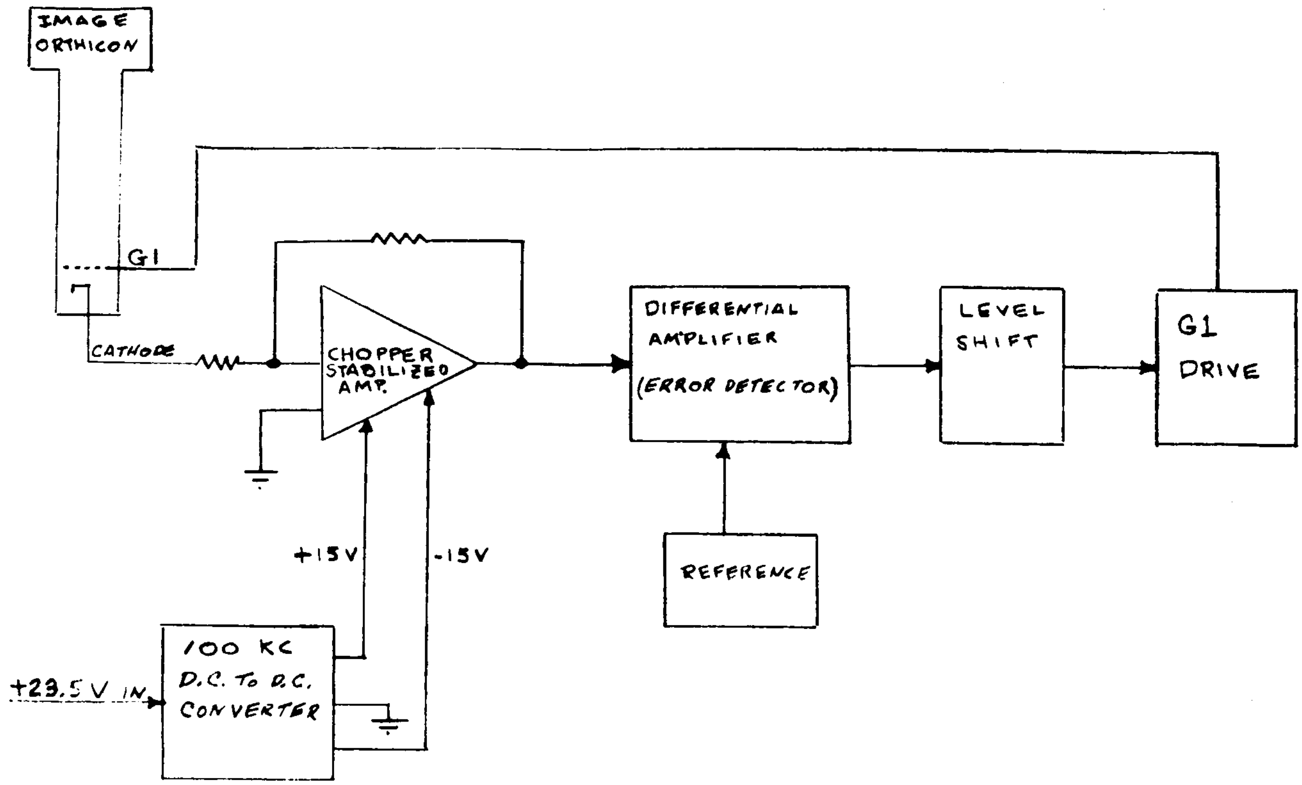


Figure 6. Cathode-Current Regulator, Block Diagram

of the comparator is level-shifted by Q4 and Q5, and connected to grid number 1 of the image orthicon tube. The electronic shutter signal is connected to the emitters of Q3 to blank the beam during exposure time. A conventional type of d-c/d-c converter, operating at approximately 120 kHz, is used to provide the potentials required by the chopper-stabilized amplifier X.

4. Fabrication

a. Anode-Sample Beam-Current Regulator

The anode-sample beam-current regulator circuitry was constructed on the same size plug-in board as the integration gate board (EI P10). Harness changes were made to accommodate either the anode-sample beam-current regulator, or the integration gate boards, in the EI P10 positions as shown in Figure 8.

b. Cathode-Sample Beam-Current Regulator

The cathode-current regulator was constructed on the same size plug-in board as the integration gate board (EI P10). Harness changes were made to accommodate either the cathode-current regulator or the integration gate boards in the EI P10 positions as shown in Figure 8.

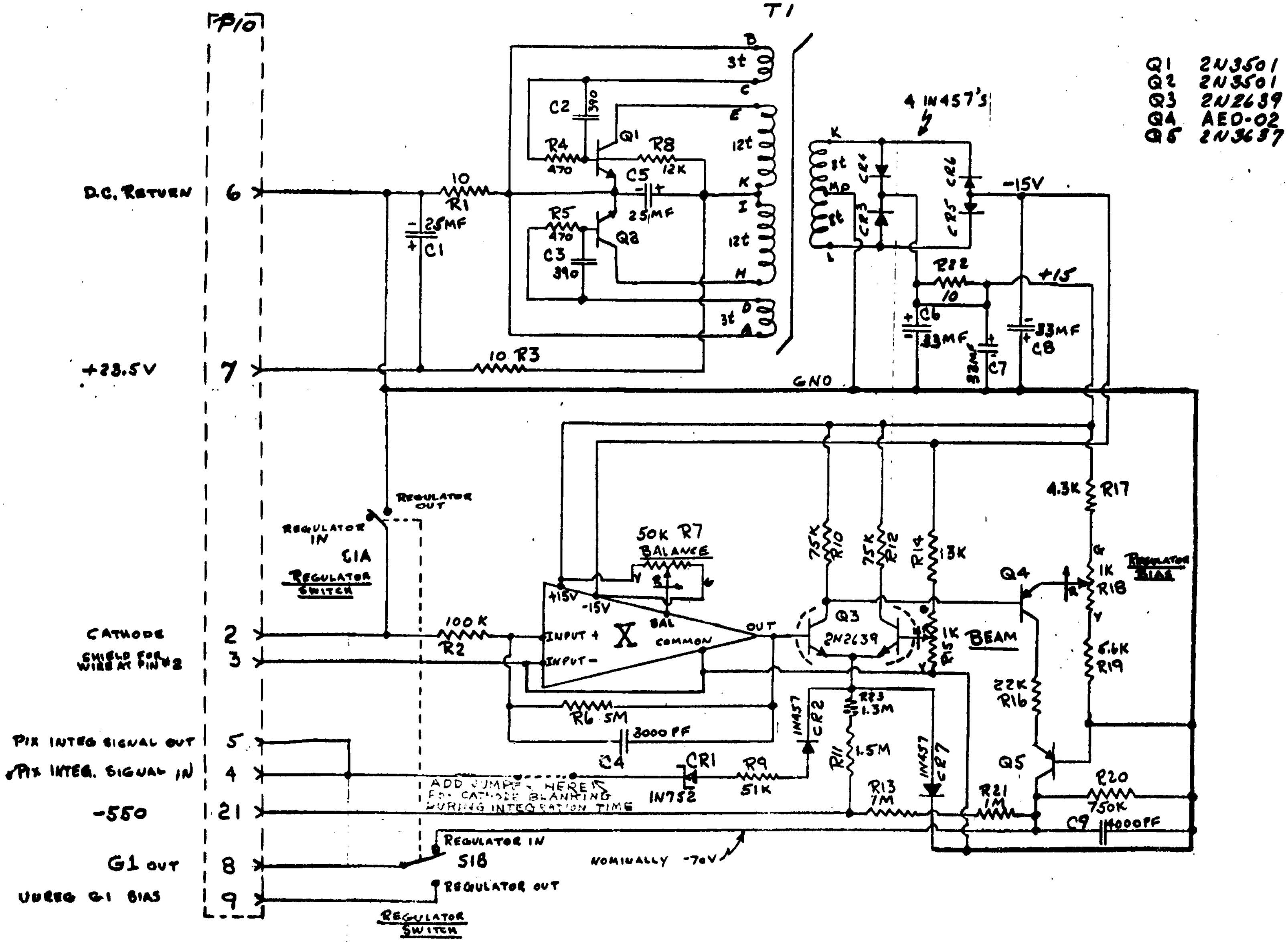


Figure 7. Cathode-Current Regulator, Schematic Diagram

	Camera Operation Mode			
	Controlled Variable Exposure - Shuttered -		Constant Exposure - Unshuttered -	
	Unreg. Beam Only	Reg. or Unreg. Beam	Unreg. Beam Only (Original Mode of Operation)	Reg. or Unreg. Beam
AIP2 Position	(1) Shutter Control (AIP2-2)	(1) Shutter Control (AIP2-2)	Programmer (AIP2-1)	Programmer (AIP2-1)
CIP6 Position SHUTTER MODE SWITCH VERT. DEFL. MODE SWITCHES	Vert. Rate & Shutter Prog. (CIP6) (2) "Manual" or "Auto" as Desired "Shuttered"	Vert. Rate & Shutter Prog. (CIP6) (2) "Manual" or "Auto" as Desired "Shuttered"	Vert. Rate & Shutter Prog. (CIP6) "Manual" "Unshuttered"	Vert. Rate & Shutter Prog. (CIP6) "Manual" "Unshuttered"
DOP7 Position R6 JUMPER C6 JUMPER R7 JUMPER C7 JUMPER	I.O. Bias Decouple-2 (DOP7) IN OUT IN OUT	I.O. Bias Decouple-2 (DOP7) IN OUT IN OUT	I.O. Bias Decouple-2 (DOP7) OUT IN OUT IN	I.O. Bias Decouple-2 (DOP7) OUT IN OUT IN
EIP10 Position	Integration Gate (EIP10-1)	Cath. Cur. Reg. (EIP10-2) or Anode Sample Beam Cur. Reg. (EIP10-3)	Integration Gate (EIP10-1)	Cath. Cur. Reg. (EIP10-2) or Anode Sample Beam Cur. Reg. (EIP10-3)
REGULATOR SWITCH	—	(3) "IN" or "OUT" As Desired (3) "IN" or "OUT" As Desired	—	(3) "IN" or "OUT" As Desired (3) "IN" or "OUT" As Desired
P18 Position	Shutter Command Timer Control Assy.	Shutter Command and Timer Control Assy.	Programmer Switch Assy.	Programmer Switch Assy.

(1) Photocathode & G6 Controls on this Board Override Similar Controls on BOP3 Board
(2) "Manual": Expose Command Required for each Exposure
"Auto": One Expose, 3 to 4 Readouts & Cycle Repeats
(3) "IN": Beam Control on this Board Overrides Similar Control on BOP3 Board
"OUT": Beam Control is Obtained from BOP3 Board.

Figure 8. Board and Switch Combinations for TIGRIS Prototype

c. Controls

Figure 9 shows the positions of the various controls on the modified TIGRIS camera.

C. ELECTRONIC SHUTTER AND SHUTTER PROGRAMMER

1. Measurements:

Data was obtained for photocathode highlight illumination versus photocathode current using two mechanical sample image orthicons. Figure 10 shows a plot of the data obtained. The curves show that, at the light levels used for the TIGRIS camera (about 10^{-7} footcandle), extremely low photocathode currents can be expected. The quantitative information obtained from this data was incorporated in the design of the electronic shutter circuitry.

2. Design

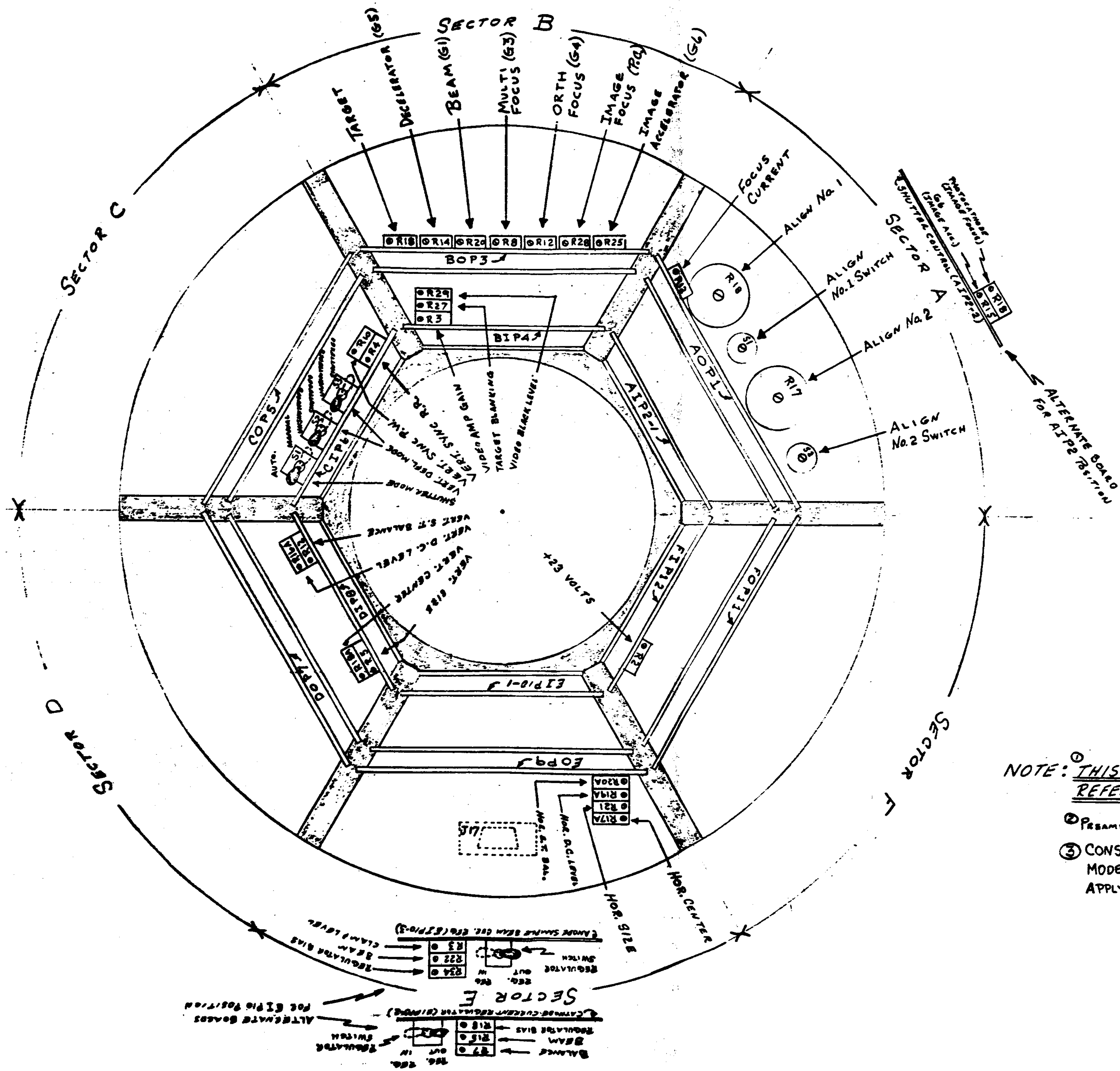
Simplified schematics of possible electronic shutter circuits were prepared. The basic principle of operation, for all the systems considered, is to gate the image section ON during the EXPOSE time. The image section is gated ON by applying a negative potential (approximately -550 volts) to the photocathode, and a negative potential (approximately 85 percent of photocathode potential) to G6 in the image section. To reduce image degradation, it was determined that the combination of rise and fall time of the "on" pulse should be a maximum of 0.01 of the shutter duration. To permit exposure durations that were originally used, the maximum exposure time was set at 16 seconds. The shortest expose time was then determined as indicated above.

As shown in the block diagram, Figure 11, the electronic shutter consists of: a programmer, a timer, a gated d-c/d-c converter, and a crowbar circuit.

3. Circuit Description

a. Shutter Control

As shown on the schematic, Figure 12, the shutter control consists of a timer, adjustable from 0.125 second to 16 seconds. It is initiated by a signal from the shutter programmer. The timer consists of a bistable multivibrator and a unijunction transistor. The programmer start trigger turns Q2 and Q4 on. This permits C2 to charge at a rate determined by the selected resistor in the timer box. When the capacitor C2 reaches its firing point, it turns Q3 on, thereby resetting the bistable multivibrator. The timer pulse from Q4 turns on Q7 which then acts as a closed switch for the emitters of the d-c/d-c



NOTE: ① THIS SKETCH IS FOR REFERENCE ONLY

② PREAMPLIFIER BOARD NOT SHOWN

③ CONSULT "CAMERA OPERATION MODE" CHECK LIST BEFORE APPLYING POWER TO CAMERA

Figure 9. TIGRIS Electronics Package Board Locations and Control Designations

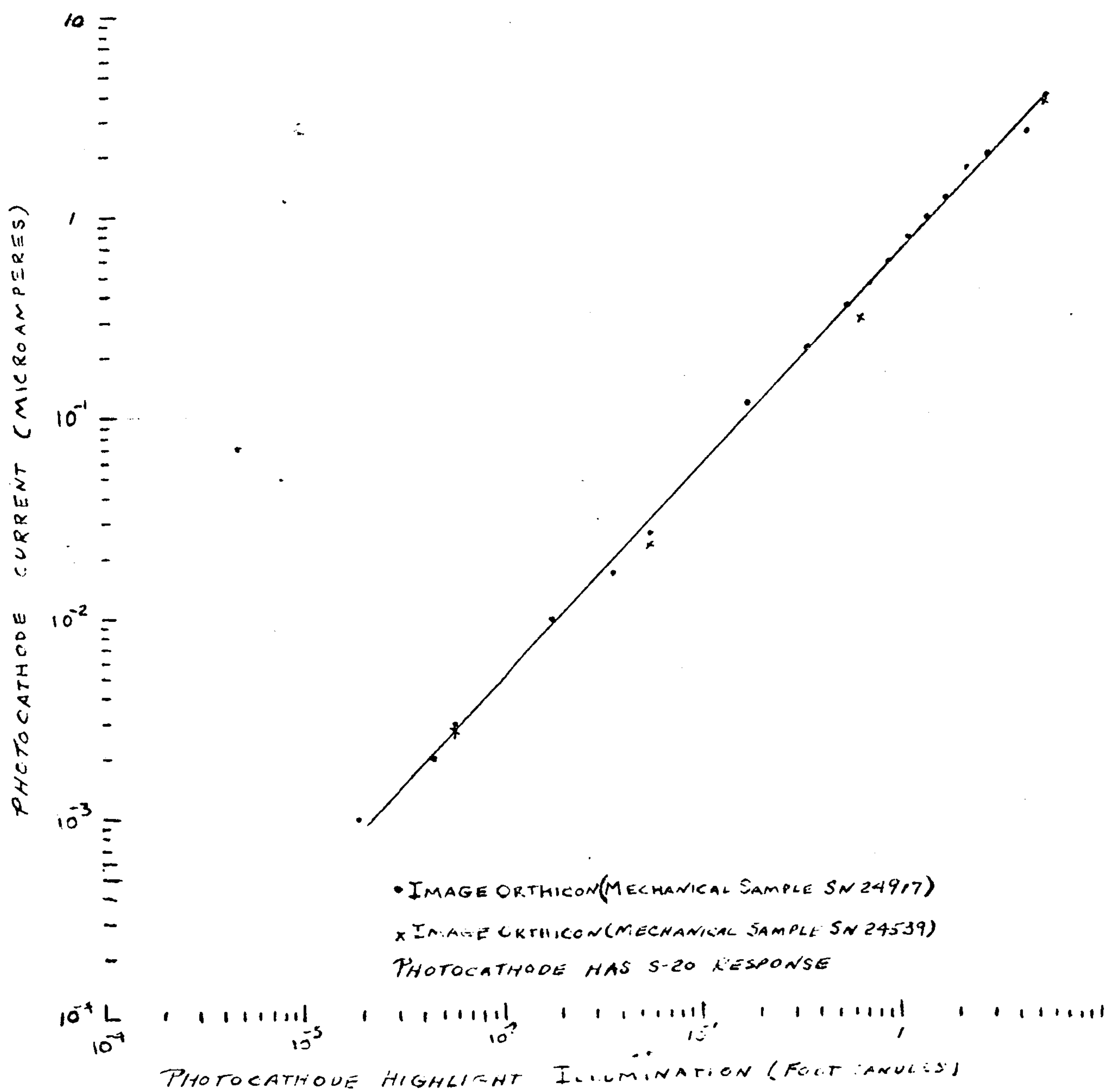


Figure 10. Photocathode Highlight Illumination vs. Photocathode Current

converter transistors Q10 and Q11. The positive edge of the timer pulse turns on Q11 to start the d-c/d-c converter. To minimize the turn-on time, a high-frequency converter is used. To decrease the turn-off time, a crowbar circuit consisting of Q8, Q9, and Q12 is connected across the photocathode and G6 electrodes and operates at the end of the expose cycle by the differentiated trailing edge of the timer pulse. Transistor Q5 is used to complete the discharge of timing capacitor C2.

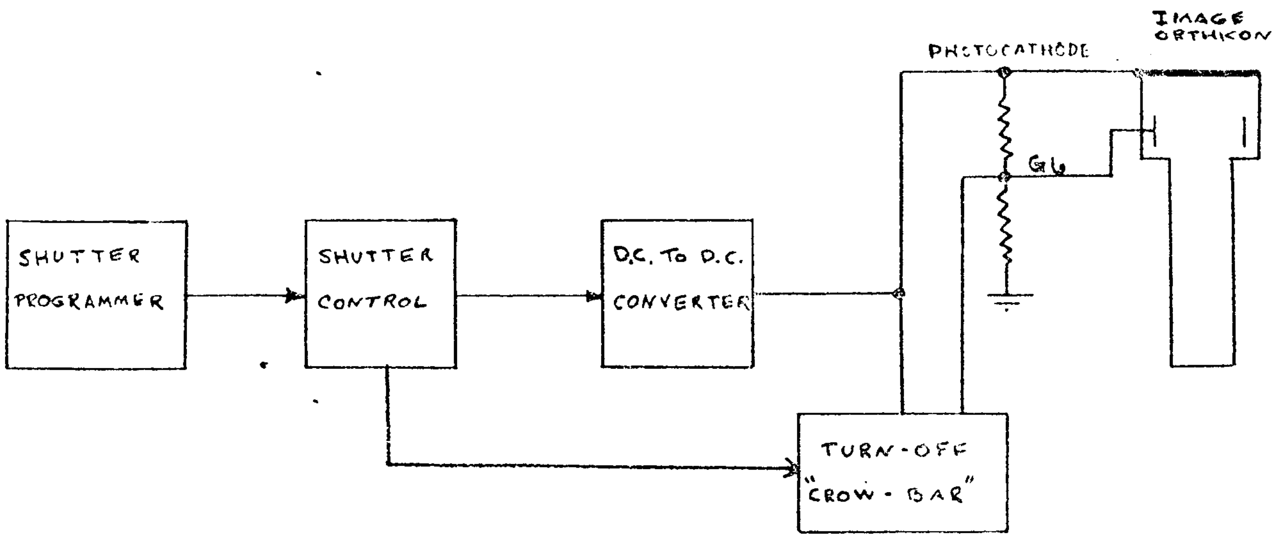


Figure 11. Electronic Shutter, Block Diagram

b. Shutter Programmer

A logic diagram of the shutter programmer is shown in Figure 13. In the manual mode of operation, position 1 of switch, an EXPOSE command is initiated by a switch in the shutter-command and timer-control box, shown in Figure 14. This EXPOSE command comes into OR gate 1, the output of which sets flip-flop 2 to its "1" state. Inverter 4 is normally high (in "1" state), gating the negative vertical rate pulse through AND gate 5. This output is inverted in inverter 6 which enables AND gates 3 and 8. The AND gate 3 changes inverter 4 to a low state and inhibits any additional negative vertical rate pulses from getting through AND gate 5. At this point, vertical deflection is stopped.

Since flip-flop 2 is now in "1" state, and the inverter 6 is high and one-shot 7 is normally high, an EXPOSE command pulse is gated through AND gate 8, which triggers the shutter command circuitry. The exposure time is determined by a switch located in the shutter-command and timer-control box. A negative-going pulse, which is directly proportional to the exposure time, is coupled to

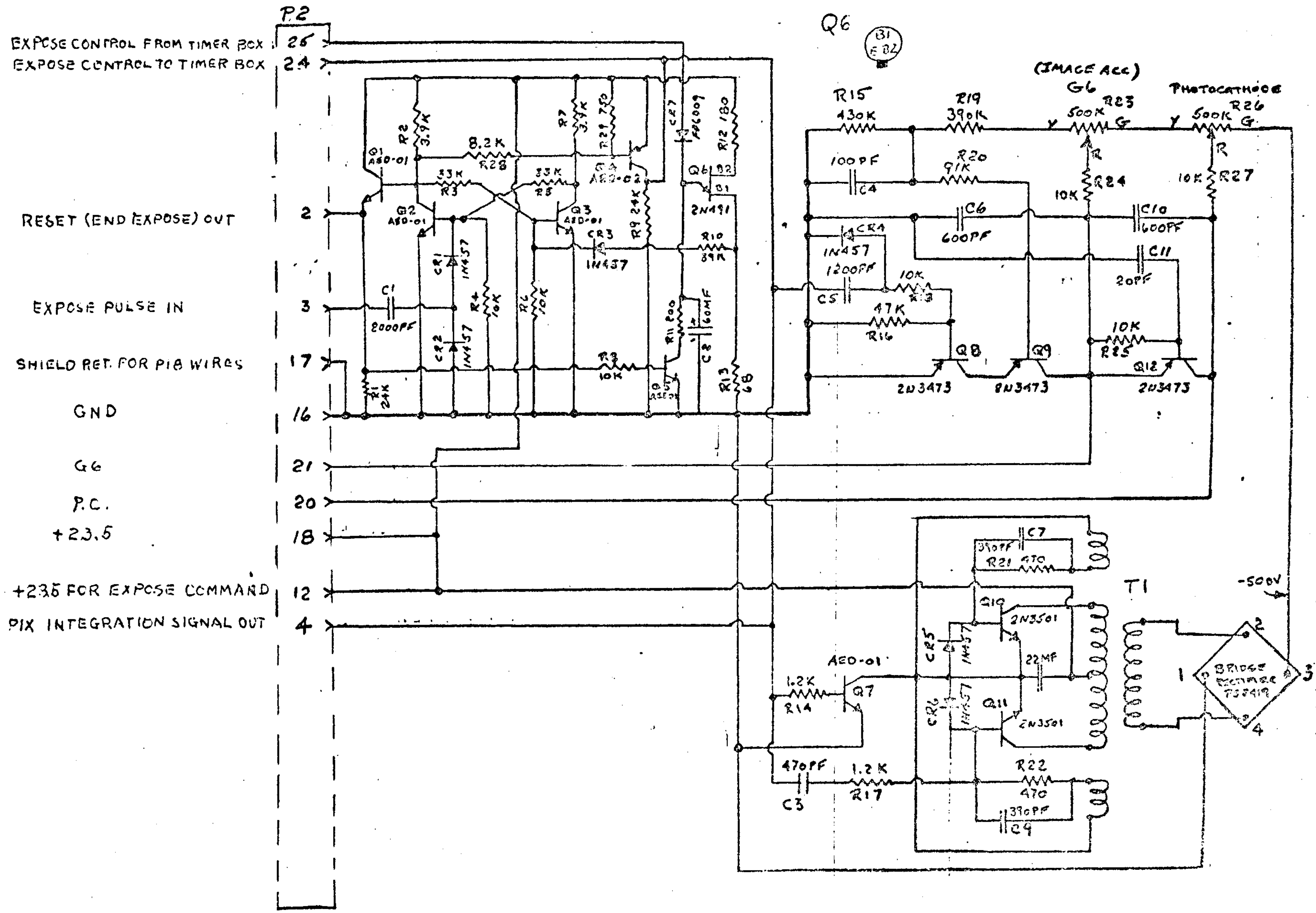


Figure 12. Shutter Control, Schematic Diagram

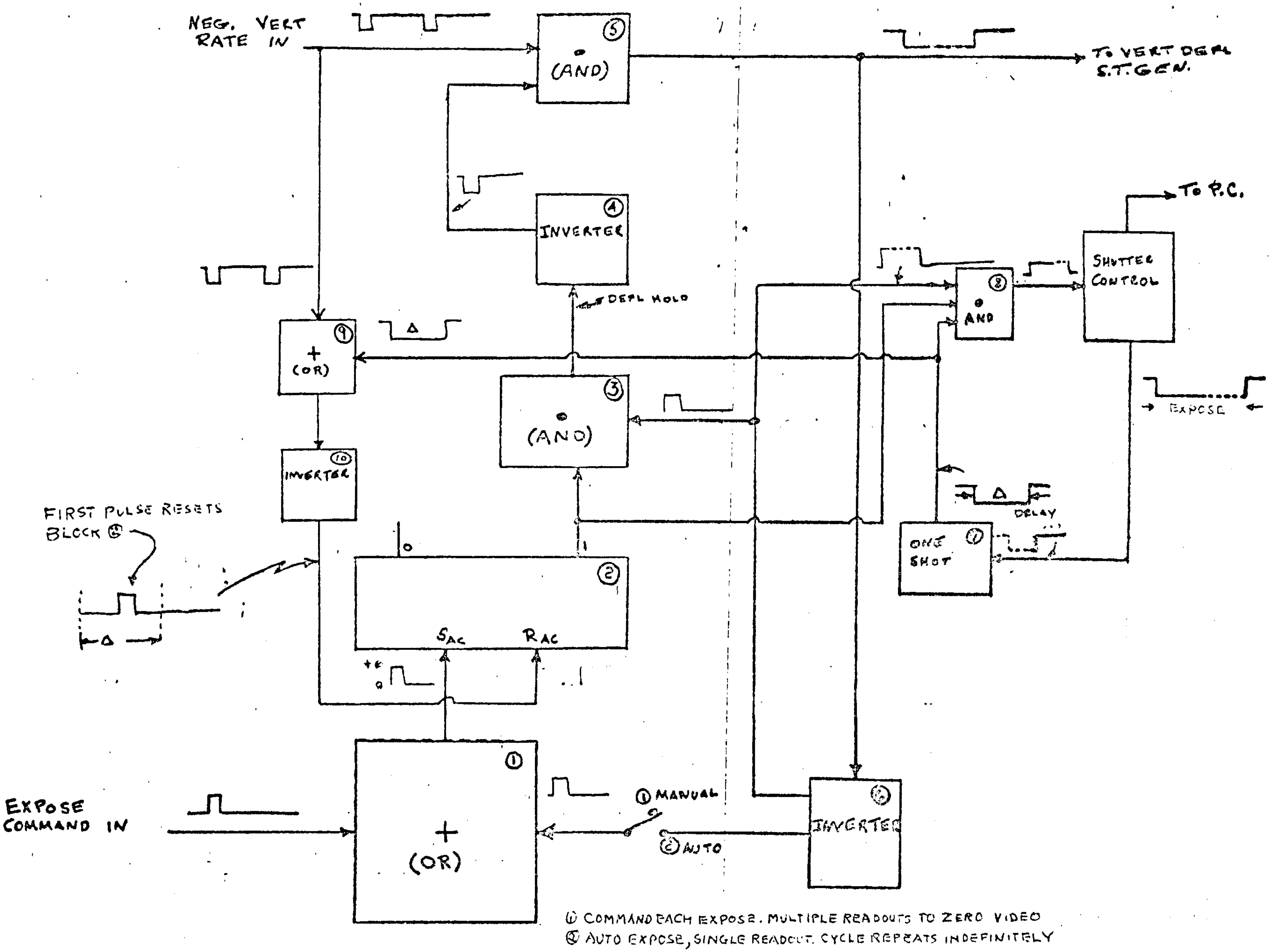


Figure 13. Shutter Programmer, Logic Diagram

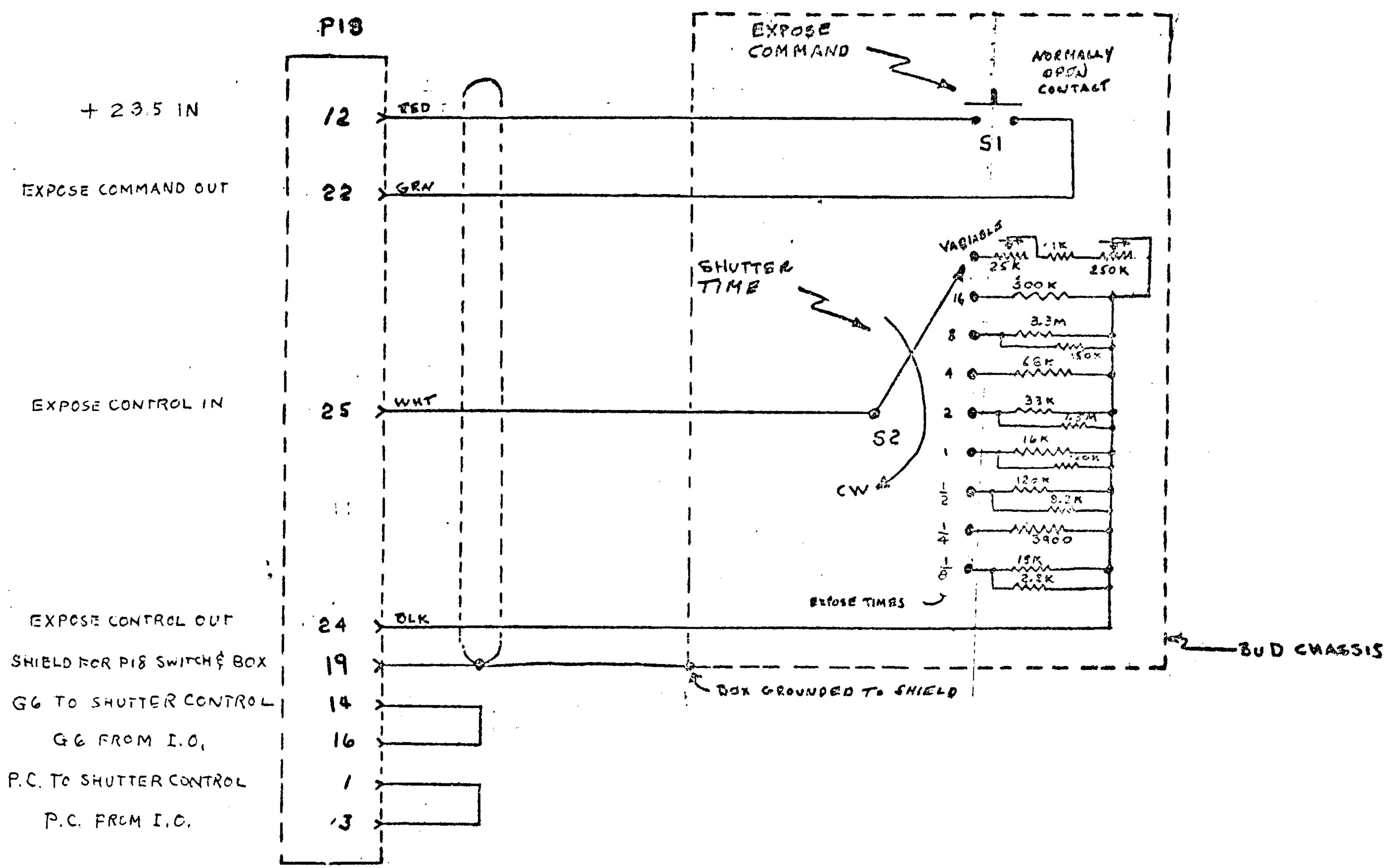


Figure 14. Shutter Command and Timer-Control Box

one-shot 7. The trailing edge of this pulse triggers one-shot 7 and disables AND gate 8 for a time equal to approximately one or two readouts of the image orthicon. One-shot 7 also drives OR gate 9. When a negative vertical rate pulse is coincident with the one-shot output, a high output from inverter 9 is obtained which resets flip-flop 2. At this point, vertical deflection starts and will continue indefinitely in this manual mode until there is another EXPOSE command input.

The automatic mode is identical to the manual mode except that the output of inverter 6 is also coupled to OR gate 1 supplying the EXPOSE command to recycle the programmer.

A schematic of the vertical rate and shutter programmer board is shown in Figure 15.

The numbers 1 through 10 in the schematic indicate circuit functions which correspond to similarly numbered logic blocks in the logic diagram described above. S1 is the manual-automatic switch shown in the logic diagram.

The vertical rate generator is coupled into the shutter programmer circuitry through switch S3 when in the shuttered operation position. S2 couples the trailing edge of the shutter control output pulse to trigger one-shot 7 as previously described. Switches S2 and S3 can also be switched to the unshuttered operation position when it is desired to operate the camera in the open shutter mode of operation, as described in Figure 8.

4. Fabrication

a. Shutter Control

The shutter-control circuitry was constructed on the same size plug-in board as the programmer board (AI P2). Harness changes were made to accommodate the shutter-control circuitry in the AI P2 position, as shown in Figure 8.

b. Shutter Programmer

The shutter-programmer circuitry was constructed on the vertical rate board (CI P6) using the extra space available on this board. Switches were added to the vertical rate circuitry to permit either shuttered or unshuttered operation of the camera. Harness changes were also made to accommodate the extra circuitry on this board.

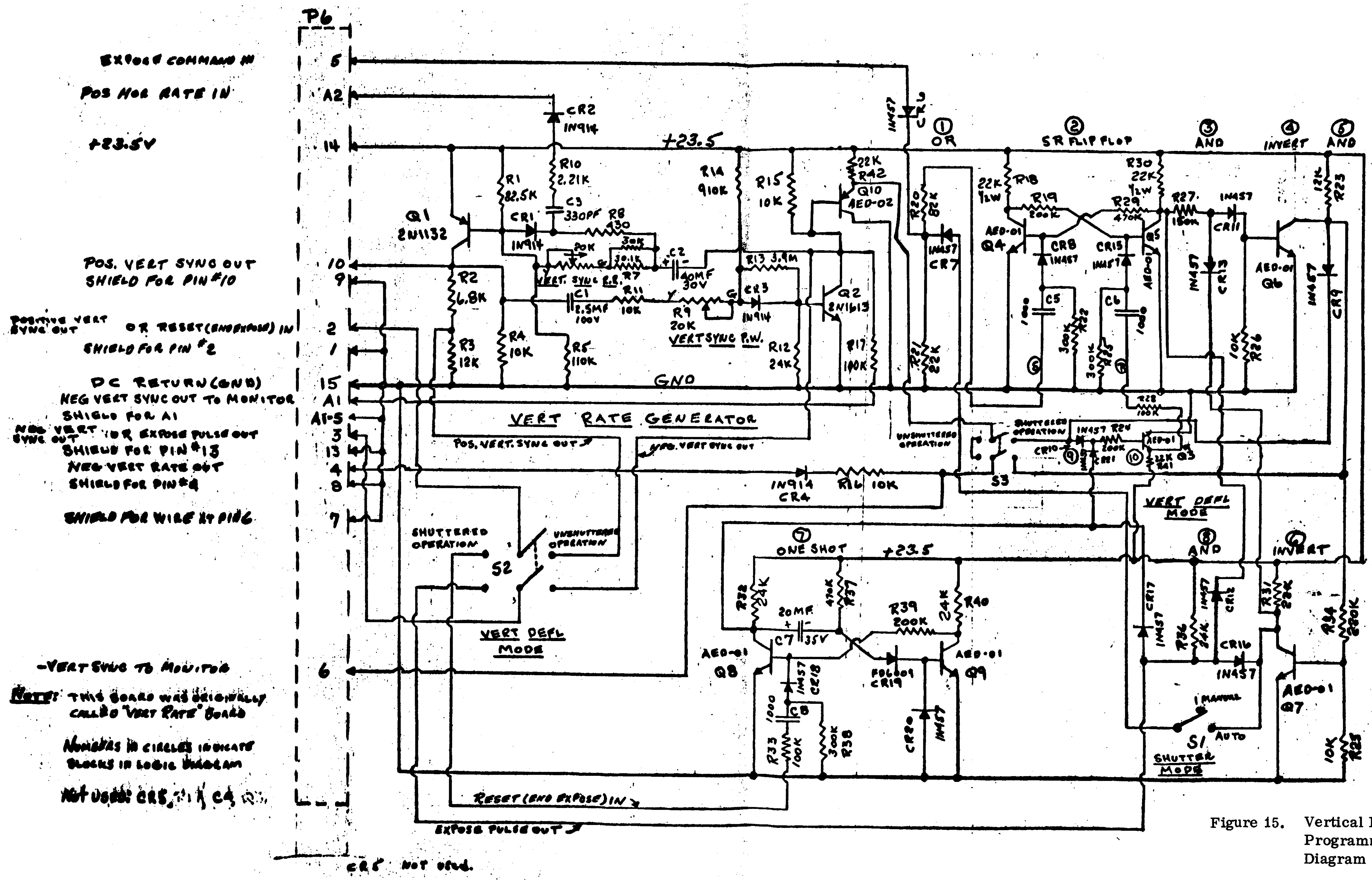


Figure 15. Vertical Rate and Shutter Programmer, Schematic Diagram

D. MAGNETIC SHIELDING

1. Measurements

To verify that additional shielding was required and to determine the amount of shielding required, measurements were made on the TIGRIS preprototype. *

The intensity of the earth's magnetic field is approximately 0.6 gauss. In a rotating vehicle, this would correspond to a flux of 1.2 gauss, peak to peak.

The measurements were conducted at a simulated flux of 2 gauss, peak to peak. The dynode spot shifted 15 percent when subjected to the test field.

View A of Figure 16 indicates the degradation in performance when the original preprototype was subjected to the test field.

2. Design

The effectiveness of a magnetic shield depends on the length-to-diameter ratio, the material, and the thickness of the material.

The larger the length-to-diameter ratio, the more effective the shield becomes.

The permeability of the material should be as high as possible.

The material should be as thick as the allowable weight permits. It has been observed, however, that very little improvement can be detected when more than three layers of high-permeability material is used.

Tests were conducted using various numbers of layers of three different materials: (1) Netic, (2) Conetic AA, and (3) Shield Mu 30. The results indicated that three wraps of either (2) or (3) were effective in the shield performance. Additional layers showed very little or almost imperceptible improvement.

3. Fabrication

It was the intention to integrate the magnetic shield into the preprototype. Measurements had indicated the same performance whether the shield was installed over the large-diameter electronics package or on the smaller-diameter camera housing.

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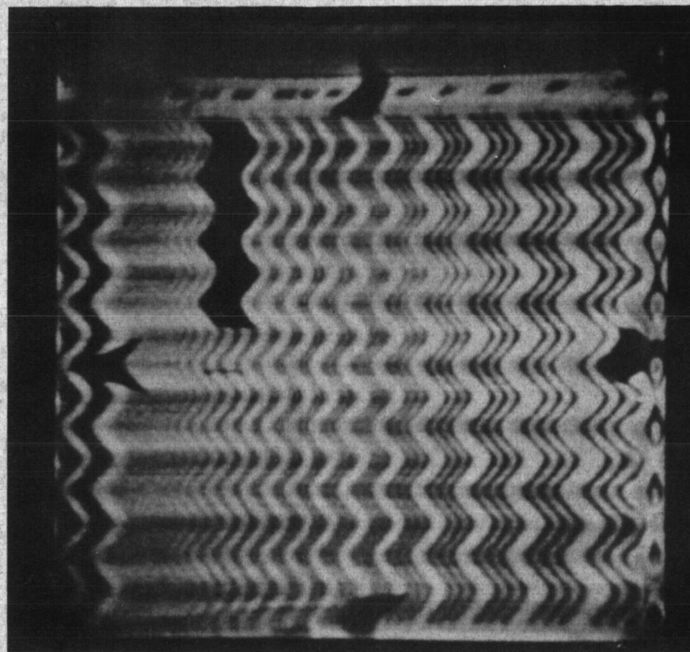
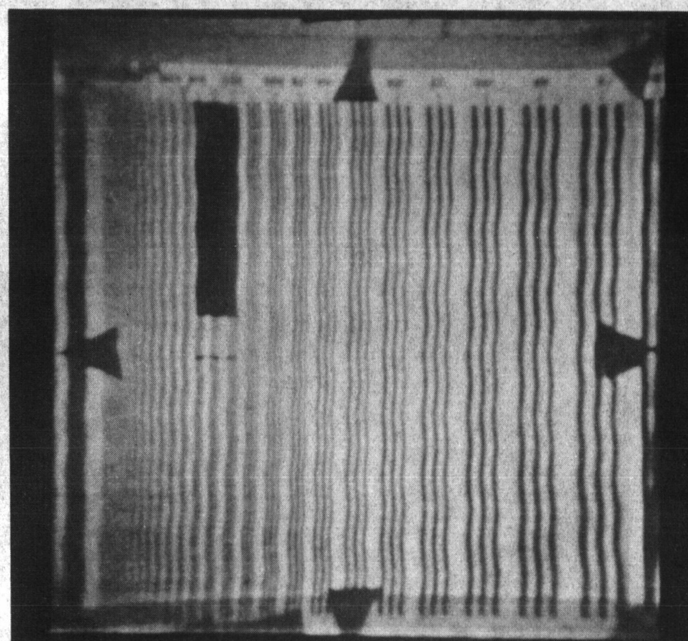
* During the field trip at Capillo Peak, it was observed that the performance of the camera changed when the camera was rotated. It was believed that this was due to disturbance from the earth's magnetic field.



A. ORIGINAL



B. ADDITIONAL SHIELDING

Figure 16. Picture Degradation vs. Magnetic Field

To integrate the shield into the preprototype, the inner diameter of the electronics package would be enlarged and the outer diameter of the camera housing would be reduced by removing the outer jacket. However, since the outer jacket has been thermally bonded to the focus coil, it was deemed to be too hazardous an operation, particularly since no spare deflection and focus assembly was available. In future units, the shield material will be integrally installed.

In the preprototype, the shield material has been hand-wrapped around the camera housing. The electronics package is operated in its optional separated mode.

SECTION III

ENGINEERING EVALUATION

A. GENERAL

The anode-sample beam-current regulator, the cathode-current regulator, and the shutter-control circuits were incorporated into the camera system as shown in Figure 8. The performance of these circuits was evaluated and the performance of the shield was checked. Individual circuit performance is discussed below.

B. BEAM-CURRENT CONTROL

1. Anode-Sample Beam-Current Regulator

A plot of G1 bias and signal-to-noise ratio versus filament-voltage for the anode-sample beam-current regulator is shown in Figure 17. The G1 bias curve is that bias required to keep a preset value of the image orthicon return-beam current constant for constant photocathode highlight illumination and varying filament voltage. The varying filament voltage was used to simulate changes in cathode emission. The image orthicon dynode gain is assumed to be constant.

The return beam is held constant down to a filament voltage of about 3.8 volts dc. Lower values of voltage across the low heater power filament produced a much lower value of return beam. This is probably due to insufficient emission from the cathode.

The slight decrease in signal-to-noise ratio as the filament potential decreased was due to a decrease in signal amplitude. The magnitude of the beam was held constant down to 3.8 volts dc on the filament. The decrease in signal might possibly be due to misalignment or poor beam-landing effects which could be introduced at the lower filament voltages. Also, at reduced filament voltages, the effective target-to-cathode potential difference could have been lessened since the electron density immediately surrounding the cathode is reduced at low filament voltages. This small effect probably would not exist for the normal operating mode where the filament potential is maintained during the mission.

2. Cathode Current Regulator

A plot of G1 bias and signal-to-noise ratio versus filament volts for the cathode current regulator is shown in Figure 18. The G1 bias curve is that bias required to keep a preset value of cathode current constant for constant photocathode highlight illumination and varying filament voltage. The varying filament voltage was used to simulate changes in cathode emission.

The actual cathode current is extremely small at the TIGRIS scan rates and photocathode illumination levels. The cathode current was, therefore, not measured directly. Instead, the criterion used to determine the performance of the cathode current regulator was the capability of maintaining a constant video signal as measured at the preamplifier output.

Reference to Figure 18 shows that the signal-to-noise ratio is held constant down to 5.5 volts across the filament. The signal-to-noise ratio then falls off significantly at lower filament voltages. This decrease was due to an increase in the beam noise and not a decrease in the signal amplitude. This condition suggests that, at reduced filament voltages, the G2-to-cathode current division ratio may decrease, permitting a higher percentage of the cathode current to get past the G2 aperture. This would increase the beam noise, even though the

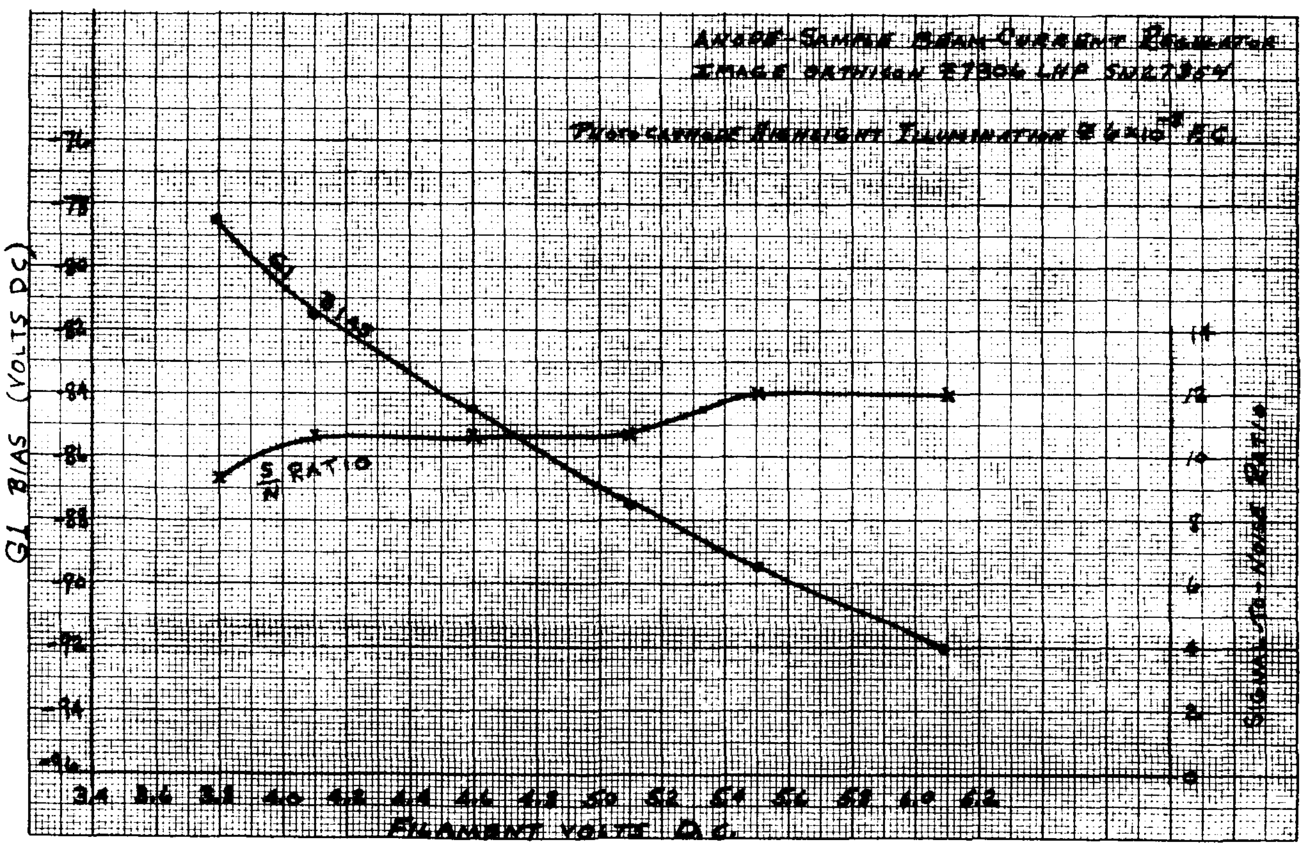


Figure 17. Signal-to-Noise Ratio and G1 Bias vs. Filament Volts (Anode-Sample Beam-Current Regulator, Unshuttered Operation)

cathode current is still maintained constant. Also, small leakage currents can cause a false error signal. The magnitude of the leakage current would not be deleterious for high cathode current types of image orthicons, or camera systems operating at rapid scan rates.

3. Comparison of Anode-Sample and Cathode-Current Regulators

The anode-sample beam-current regulator samples the return beam at a line rate and maintains the return beam constant at a predetermined value. This means that there will always be sufficient beam to discharge the target over the range of filament voltages used. This beam current is not dependent on any variable G2-to-cathode current division which may be present, or cathode leakage currents.

The cathode-current regulator, on the other hand, will maintain the cathode-current constant but not necessarily the beam current, due to a possibly variable G2-to-cathode current division at lower filament voltages. For short missions, neither of these conditions is likely to exist.

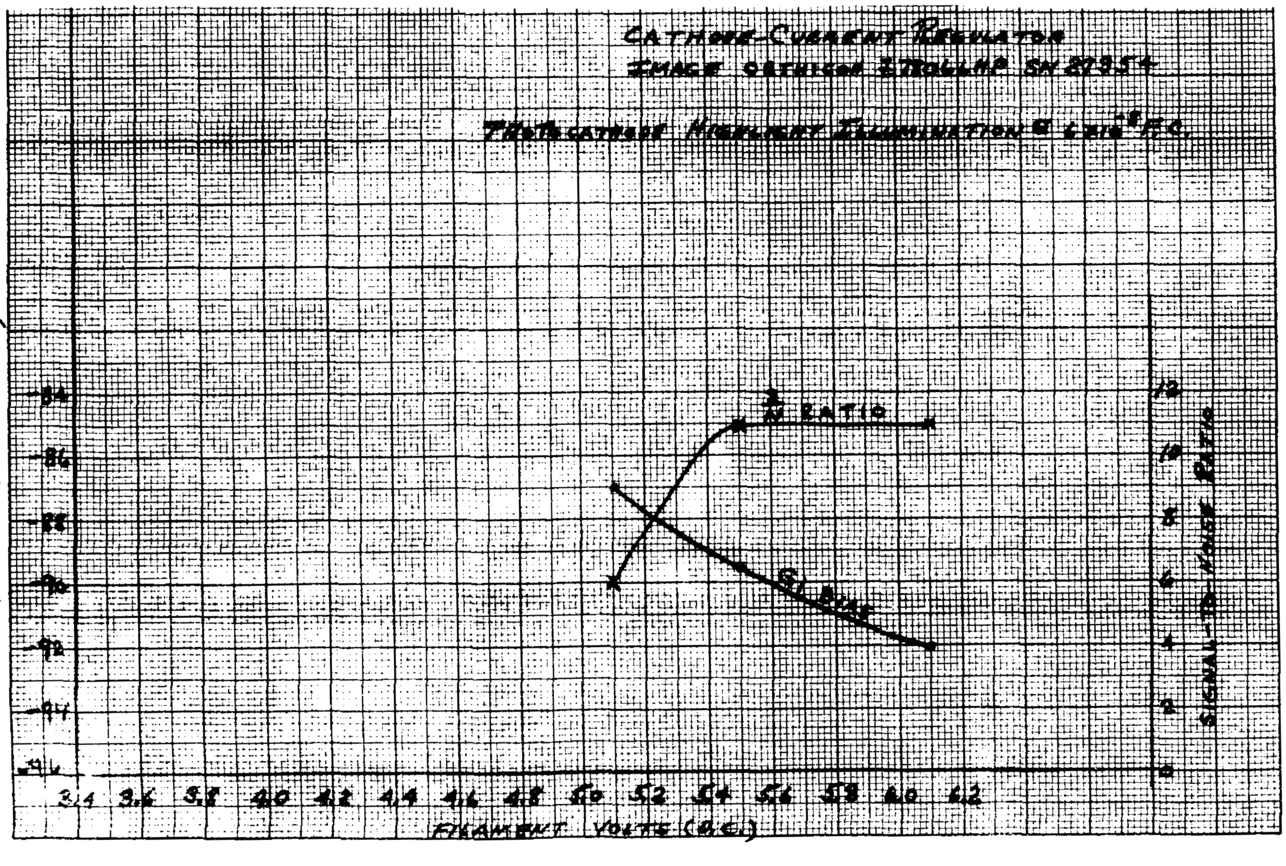


Figure 18. Signal-to-Noise Ratio and G1 Bias vs. Filament Volts (Cathode-Current Regulator, Unshuttered Operation)

It is expected that the settling time (after exposure) of the anode-sample regulator could be improved by using a dual field effect transistor in the sample-and-hold circuit. A type 2N3954 was announced too late for trial.

C. ELECTRONIC SHUTTER

The turn-on time of the electronic shutter is approximately 900 microseconds and the turn-off time is approximately 8 microseconds. The nominal shutter pulse width (expose time) is manually adjustable to values of 1/8, 1/4, 1/2, 1, 2, 4, 8 and 16 seconds. Continuous adjustment from 0.07 to 17.4 seconds is also provided on the preprototype camera.

Since the anode-sample beam-current regulator appeared to be the preferred method of beam-current control for long missions, it was used in the evaluation of the performance of the electronic shutter.

Figure 19 shows a plot of image orthicon photomultiplier anode current versus photocathode highlight illumination for various shutter (exposure) times. The type of scene material used for the measurements is shown at the bottom of the plot. The equivalent beam noise at the output of the image orthicon for this data is approximately 2.18 nanoamperes, peak to peak; dividing by 6 gives about 0.36 nanoampere rms. Signal measurements were made at the preamplifier output. The gain is 89 and the bandwidth extends to 100 kilohertz.

As noted in the figure, the beam current was held constant for all exposure times. The range of light levels over which the camera system has significant sensitivity is about 700,000:1 for the shutter speeds used. The signal-to-noise ratio over this range varied from about 1.5:1 to about 17:1.

It should be pointed out that the TIGRIS prototype camera is designed to use a 3-inch image orthicon which has been properly potted to insure proper orientation of the tube in the focus coil and deflection yoke assembly. The tube that was used to obtain the sensitivity data was not potted due to the fact that the tube had a known mechanical strain toward the front end which might have become aggravated if it were potted. In addition, the tube is a borrowed item and thus could not have been returned in an acceptable condition to the vendor. Therefore, the tube was secured in the focus coil and deflection yoke assembly using mechanical positioning devices to approximate the required accurate positioning of the tube within the assembly. Toward the end of the program, it was found that the tube had shifted slightly from its original position in the yoke assembly. The data recorded in Figure 19 had been taken with the tube in the slightly shifted position.

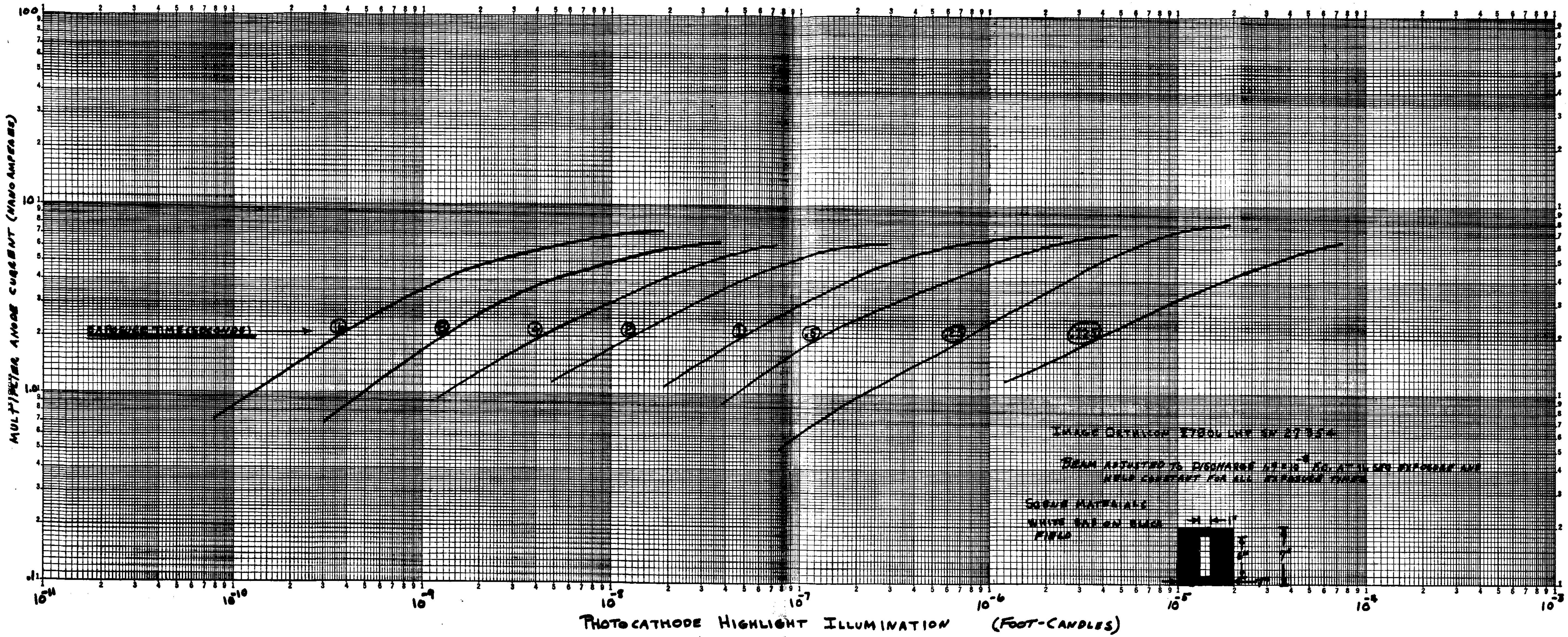


Figure 19. Multiplier Anode Current vs. Photocathode Highlight Illumination (Shuttered Operation)

A comparison of Figure 19 with Figure 3 (this data taken under proper tube-positioning conditions) shows that the approximate "first knee" for 2-second open shutter, or 2-second shuttered operation, is still at approximately 2×10^{-7} footcandle. The photomultiplier anode current, however, is down by about 4:1 at this light level. The tube was repositioned and spot checks were made on the sensitivity. The sensitivity had increased substantially, but the shape of the curves appeared to remain unchanged. Consequently, the data shown in Figure 19 could be interpreted as pessimistic in that higher signal-to-noise ratios could be expected than those indicated.

Figure 20 is a plot of photocathode highlight illumination versus exposure time to maintain a constant signal output from the photomultiplier anode. The beam setting and scene material are indicated in the Figure. The data shows that about a 4:1 change in exposure time is required for a 10:1 change in photocathode highlight illumination. This curve could be considered as an indirect measurement of the image orthicon gamma (ratio of change in signal current to change in photocathode highlight illumination when plotted on log coordinates) since, instead of change in signal current, we have change in exposure time to produce constant signal current. Figure 20 thus serves as a cross check on the data shown in Figure 19.

D. MAGNETIC SHIELDING

The magnetic shielding was tested by applying (a) a d-c field and (b) an a-c field.

The shield reduced the shift of the return-beam dynode spot from fifteen percent to less than two percent with an applied d-c field of 1 gauss.

The photographs of Figure 16 show the results of the shield performance. The test field is 2 gauss peak to peak at 5 hertz which is the worst case observed. View A shows the original performance. View B shows the greatly improved performance with shielding. As pointed out in a previous section, further shielding produces very little improvement.

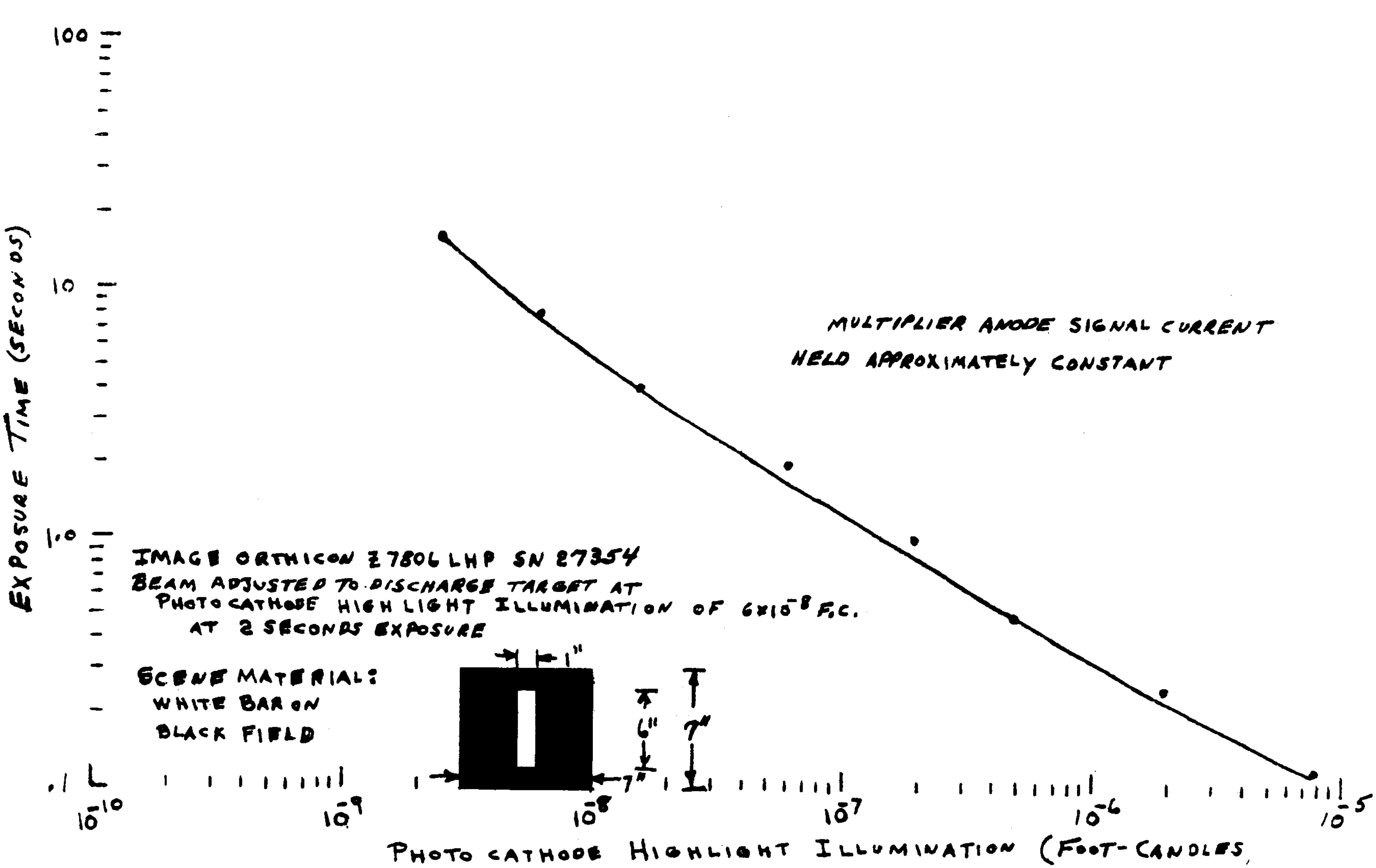


Figure 20. Exposure Time vs. Photocathode Highlight Illumination

SECTION IV
DEMONSTRATION

A demonstration of the improvements incorporated in the TIGRIS image orthicon camera system was held on August 24, 1966. An outline of what was encompassed by the demonstration is given below.

A. REVIEW OF WORK PERFORMED

(1) Beam current control

(2) Electronic shutter

(3) Magnetic shielding

(4) Shading investigation and recommendations

(5) Automatic exposure control recommendations

(6) Black halation recommendations

B. DEMONSTRATION

1. Beam Current Control (Unshuttered)

(1) None. Original unregulated mode.

(2) Cathode-current regulator.

(3) Anode-sample regulator. Filament potential is changed to simulate changes in cathode emission.

2. Electronic Shutter

The exposure time was changed and corresponding changes in illumination (as modified by tube gamma) were made. The result was an approximately constant video output signal.

3. Magnetic-Shield Performance

A simulated magnetic field was applied and the slight degradation in performance was observed. The shield was then removed and the test repeated. The intolerable performance without the shield was noted.

SECTION V
OTHER RECOMMENDATIONS

A. FIELD TRIP

It is recommended that a field trip be conducted at a suitable location, such as the Kit Peak National Observatory in Tucson, Arizona, to test the effectiveness of the improvements that have been incorporated. The results of the original field trip to Capillo Peak were very helpful in formulating the improvement program.

A second monitor incorporating a short-persistence-phosphor cathode-ray tube would be very useful on such a field trip.

B. ELECTRONIC SHUTTER

The present range of 125 milliseconds to 16 seconds is useful for many applications.

In a rotating vehicle, however, shutter speeds of 10 milliseconds and less are desirable to prevent image smear due to the relative motion of the camera to the scene.

Therefore it is recommended that an electronic shutter be developed having shutter speeds of 10 microseconds to 1 millisecond. This would permit, for example, taking cloud cover pictures during the day or night from a spin-stabilized satellite.

C. BEAM CONTROL

With the exception of the settling time after exposure, the anode-sample regulator appears to be superior to the cathode beam-current regulator. Therefore, it is recommended that a field effect transistor sample-and hold circuit be developed and tested to improve the settling time characteristic of the anode sample regulator. A matched pair field effect transistor became available too late for its use in the original design.

D. VIDEO FEEDBACK

Video feedback, to the grid of the image orthicon, has been tried by General Electric and RCA to extend the dynamic range. These investigations have shown some shortcomings. With the inclusion of the anode-sample regulator it is probable that a video feedback system could be applied. Some tests using video feedback to the target showed very promising results.

It is recommended that the advantages of video feedback to the target or grid be investigated now that the beam current has been well regulated.

E. MONITOR

It is recommended that a second monitor be provided that would incorporate a rapid decay phosphor for photographic purposes. It should include overscan and gamma correction circuits.

F. PERMANENT MAGNET FOCUS

The focus power for the image orthicon is 28 watts, which is over half of the total power requirements. It is recommended that a permanent magnet focus assembly be tested.

G. APT READOUT*

It is recommended that tests be conducted in reading out the picture at APT rates. If this technique is successful, it would be possible to take cloud photographs by starlight without the use of an IR sensor and allow these pictures to be received by the numerous simple and inexpensive APT ground stations.

H. QUALIFICATION TESTING

The recent success of the Aerobee 350 vehicle suggests that it would be appropriate at the present time to review the expected environmental requirements for a TIGRIS camera mounted in an Aerobee 350. It is recommended that the TIGRIS preprototype camera be modified to meet the environmental requirements and then be subjected to qualification tests.

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* APT is a slow-scan television system which permits transmission of high-quality pictures at very low bandwidths (1.6 kilohertz). This allows the use of a very low-cost ground station consisting of an antenna and receiver plus a facsimile readout.

SECTION VI
REFERENCES

1. RCA Letter Progress Report Number 12; October 7, 1964; Contract No. NASW-823

2. TIGRIS Field Trip Test Report; T. Gold, CDSR

3. RCA Final Engineering Report AED R-2583; January 15, 1965; Contract No. NASW-823

4. Proposal, "Modification of TIGRIS Image Orthicon Camera", Radio Corporation of America, AED 915070-A; June 28, 1965